Numerical Weather Prediction

The Effectiveness of the AIRS Bias Correction for Various Air-Mass Predictor Combinations

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Abstract

The effectiveness of the AIRS bias correction is studied for various combinations of air-mass predictors. Bias corrections were generated for three different periods: April 2003, mid-November to mid-December 2002 and mid-January to mid-February 2003. It is demonstrated that a scan-only bias correction performs poorly and that at least a few air-mass predictors should be used. The use of modelled channel radiance as a predictor results in a noticeable reduction in the standard deviation of the observed minus background radiances in channels important for the retrieval of water vapour information. It is recommended that predictor combinations 1+2 (200–50 hPa thickness and 850–300 hPa thickness) and 1+2+5 (200–50 hPa thickness, 850–300 hPa thickness and the modelled channel radiance) are both tested in trial assimilations.

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1 Introduction

It is planned to assimilate AIRS radiances using a variational data assimilation scheme. One of the assumptions of variational data assimilation is that the expectation value of the difference between the real and simulated observations is zero; in other words the errors are unbiased. In practice systematic biases will exist due to miscalibrations in the observing instrument, systematic errors in the background field and systematic errors in the radiative transfer model (systematic biases from assuming the distribution of chemical species not included in the NWP model, such as ozone, or estimating the temperature distribution of the atmosphere above the model top may be classified as a deficiency in the background field or in the radiative transfer model). The aim of the AIRS radiance bias correction is to remove these systematic biases.

The current AIRS bias correction scheme can be divided into two main components: a scan angle dependent correction and an air-mass dependent correction. The bias correction removes any scan angle dependence by subtracting a different constant offset for each scan position. The air-mass dependence is removed by subtracting a linear function of quantities sensitive to the air mass, known as air-mass predictors.

This report describes the efforts made to identify the best combination of predictors to use in the bias correction. The code which was used to compute the bias correction parameters is described in section 2 and the data used in the investigation is discussed in section 3. The magnitude of the AIRS scan bias is briefly considered in section 4 before proceeding to investigate the effect of different air-mass predictor combinations using April 2003 data in section 5. The results for November 2002/December 2003 and January/February 2003 are given in section 6.

2 The Bias Correction Code

The AIRS bias correction is computed by a set of Unix scripts and Fortran code assembled by Brett Harris (BoM) and adapted from BoM and ECMWF code [1][2]. This code is designed to remove a bias that not only varies from channel to channel but may also vary with the scan position and the air-mass of each observation. The scan angle dependence is fitted by allowing a different constant offset for each scan position. The air-mass dependence is included by performing a linear fit to quantities sensitive to the type of air mass; these quantities are known as air-mass predictors. A useful air-mass predictor is one that correlates well with the degree of systematic error.

6 air-mass predictors were used in this study, each of which has an associated number and 8 character name. The scan-only bias correction, which does not use any predictors, is labelled zero in this report and has been added to the list of predictors for completeness. The predictors are:

0 scan-only The scan-only bias correction, meaning that no predictors were used.

1 thick200 200–50 hPa thickness.

2 thick850 850–300 hPa thickness.

3 skintemp Skin temperature.

5 britemp The modelled radiance for the channel in question.

7 thick1k 1000-500 hPa thickness.

8 latitude The latitude of the observation.

The predictors are mostly referred to by their numbers from here on. Note that predictor 8 will only correct a linearly varying north/south dipole. It would be preferable to avoid relying on predictor 3, skin temperature, because it is not likely to be that accurate over land and, looking to the future, we would prefer a bias correction that works equally well over land as over sea. Similarly, the modelled brightness temperature for channels sensitive to the surface will not necessarily be all that accurate over land.

The bias correction code supports three different schemes: a scan-only correction, a residual correction and a combined correction. The scan-only bias correction simply calculates the mean observed minus background brightness temperature (O-B) bias for each scan position and does not take into account any air-mass dependence. The residual scheme first calculates the mean O-B bias for each scan position, subtracts it off and then performs a linear fit of the predictors to the residual bias. The combined scheme calculates a constant offset for each scan position and a coefficient for each predictor all in the one linear regression. This report only makes use of the scan-only and combined schemes. The scan-only corrections are labelled with a '0' in the figures while the combined corrections are identified by the predictor numbers used in the fit, for example '1+2'.

The bias correction code does not use the full data set to compute the bias parameters, instead, a thinned data set is used where the amount of thinning depends on the latitude. Five latitude bands are defined: 90S–60S, 60S–30S, 30S–30N, 30N–60N and 60N–90N. To thin the data, the n^{th} observation in each latitude band is kept and used in the bias calculation. The default values for n are 1, 7, 21 ,2 1 for each latitude band respectively. The disparity in thinning between the 60S–30S and 30N–60N band is because of their different land:sea ratios.

After the data has been thinned, four quality control checks are applied: the data must be over the sea (the model surface type is used to reject sea-ice), the observed brightness temperature must be between 130 and 350 K (the lower limit has been reduced from the original setting of 150 K to allow for the coolest brightness temperatures from AMSU-A channels 1 and 2), the absolute O-B must not be greater than 20 K and the O-B must not be more than three standard deviations from the mean O-B, where the mean and standard deviation are computed from an initial

loop using the first three checks only. The bias correction parameters are then computed using the thinned, quality controlled observations.

Once the bias parameters have been computed, the derived correction is applied to the full set of data without any thinning. Statistics on the mean and standard deviation of the uncorrected and corrected O-B for each channel, each latitude land and for all latitude bands are written out to a file for inspection. These statistics are the basis for most of the plots in this report. Maps showing the mean and standard deviation of the uncorrected and corrected O-B may also be generated, see figure 1. In the ideal case, the mean corrected O-B would be zero world-wide. Clearly the latitude band statistics do not give as detailed information on the geographical variation as the maps but they are more convenient for investigating large numbers of channels.

3 Data

Data from three different periods was used to investigate the AIRS and Aqua AMSU-A bias correction: 1^{st}–30^{th} April 2003, 17^{th} November – 15^{th} December 2002 and 16^{th} January – 15^{th} February 2003. A data set containing only clear fields of view was collected for each of these periods. The November/December and January/February dates were chosen because they are before and after the period selected for a trial assimilation of AIRS data: 16^{th} December 2002 – 13^{th} January 2003. The November/December data is slightly suspect in that the cloud detection and temperature extrapolation above the model top were changed during that period. April is not the ideal month to test the bias correction because there will be little global asymmetry from the presence of a winter hemisphere and a summer hemisphere. Clear fields of view were identified using the AIRS cloud detection scheme [3] (in fact, the test was that none of the quality control bits for the AIRS monitoring were set). Using the clear data sets, 117 AIRS channels and all 15 AMSU-A channels were bias corrected using various combinations of the predictors. These channels are variously referred to by their bias index, AIRS monitoring index and absolute AIRS channel number — figure 2 contains a conversion table. An early result, that causes some concern, was that the skin temperature predictor (3) was surprisingly effective in bias correcting the upper atmosphere. One of the proposed mechanisms that could cause the upper atmosphere's characteristics to depend on the skin temperature is through the selective effects of the cloud detection scheme but more likely it is just acting as a crude latitude predictor (see figure 6). As microwave data is fairly insensitive to cloud, the cloud detection scheme may be bypassed and this hypothesis can be tested. With this in mind, a second April data set was collected with no cloud detection applied (testing that no AIRS monitoring quality control bits were set, ignoring the state of bit 1 – cloudy spot, bit 2 – high cloud and bit 26 – no channels for retrieval). The clear + cloudy data file was thinned so that the statistics in each of five latitude bands were similar to that of the clear April data (after quality control). To thin the data, the n^{th} observation in each latitude band was kept, dropping all the others. The values of n which gave a reasonable match were 47, 15, 7, 16 and 34 for each latitude band respectively. Using this clear + cloudy data set, the 15 AMSU-A channels were bias corrected for various predictor combinations. From here on, the clear April data is either be referred to as April data or AIRS+MW, the clear + cloudy April data as MW

	Bad O	Bad O-B	3σ	Passed
AIRS+MW	0	305	7611	234862
MW C+C	0	3406	1551	214344
Nov/Dec	0	894	5611	200902
Jan/Feb	0	175	6271	203585

Table 1: Table showing the number of observations which fail three of the quality control checks together with the number that pass (the 'pass' rate is slightly deceptive in that all channels that are dropped by the thinning process are counted as having passed). The Bad O test demands that the observed radiance be between 130 and 350 K, the Bad O-B test that the absolute observed minus background (O-B) be less than 20 K and the 3σ test demands that the O-B must not be more than 3 standard deviations from the mean.

	90S–60S	60S–30S	30S–30N	30N–60N	60N–90N	Global
AIRS+MW						
Total	3935	50468	158164	20222	2073	234862
Thinned	3935	5873	5811	9157	2073	26849
MW C+C						
Total	3893	46584	141661	20131	2075	214344
Thinned	3893	5750	6008	9214	2075	26940
Nov/Dec						
Total	1135	37977	137721	20955	3114	200902
Thinned	1135	4665	5516	9543	3114	23973
Jan/Feb						
Total	4189	48994	133838	15940	624	203585
Thinned	4189	5951	5144	6867	624	22775

Table 2: Table showing the total and thinned number of observations in each latitude band for the four categories of bias correction.

C+C, the clear November and December data Nov/Dec and the clear January and February data Jan/Feb. Table 1 shows the number of observations failing the quality control for the four categories of bias correction while table 2 shows the latitude band distribution of the passed observations.

4 The Scan Bias

The subset of AIRS radiances received from NESDIS come from only 30 of the 90 possible scan positions (positions 2, 5, 8 ... 89). The top plot in figure 3 shows the number of observations in each scan position used in the Jan/Feb and April bias corrections. The middle plot shows the scan bias relative to the average bias of the central two scan positions (44 and 47) for the 117 bias corrected AIRS channels. The bottom plot shows the relative scan bias of the 15 AMSU-A channels. Figure 4 compares the relative scan bias of the 117 bias corrected AIRS channels in Jan/Feb with the scan bias in April. It can be seen that the general features of the scan bias pattern persist over this period and are not due to random effects.

There will be no benefit from bias correcting to much better than than the random error in the difference between the observed and simulated radiances. Figure 5 shows the uncertainty in the observed brightness temperature due to channel noise for a 250 K scene for the AIRS bias channels. The contribution to the random error from the forward model is hard to estimate but is assumed to be in the region of 0.2 K. Comparing figures 3 and 5 and bearing in mind the likely forward model error, it can be seen that the case for carrying out a scan bias correction for AIRS channels is weak but may be of benefit in a few cases. The bias correction code currently treats AIRS and AMSU channels in the same way and a scan bias correction is certainly required for the AMSU channels. The scan bias correction for AIRS channels has been retained for the time being.

5 Results for April Data

Figure 7 compares the uncorrected mean observed minus background (O-B) bias observed in the 117 AIRS channels using clear April data (top plot) with the difference between the University of Wisconsin's High Resolution Interferometer Sounder (HIS) and GENLN2 (bottom plot). The HIS/GENLN2 data is taken from a detailed comparison of HIS with line-by-line models [4]. The x-axis values are the 117 bias corrected AIRS channels, see figure 2 for the conversion to absolute channel number. As the HIS channels are not at exactly the same frequencies as the AIRS channels, the O-B was linearly interpolated to the AIRS frequency using the two HIS channels on either side. The maximum absolute HIS-GENLN2 difference of the two surrounding channels is also plotted. There was an intensive observing campaign coinciding with the HIS flight, so the atmospheric profile used in GENLN2 can be considered to be well characterised. Of course, HIS is a different instrument to AIRS and will have a different response, HIS was flown at 20 km while AIRS is in orbit and GENLN2 is a line-by-line model rather than a fast model like RTTOV but, nevertheless, the AIRS biases look like the right magnitude for errors in a radiative transfer model.

Figure 8 displays four plots for the AIRS+MW (April) bias correction, showing the AIRS channels only. The top plot shows the uncorrected mean O-B (black dashed) and the corrected mean O-B (solid colour) when using different combinations of predictors. The second plot is a close-up of the top plot but without the uncorrected O-B. The third plot shows the standard deviation of the uncorrected and corrected O-B while the fourth plot shows the corrected standard deviation of O-B as a percentage of the uncorrected standard deviation. Note that the mean O-B is not constrained to zero and the corrected standard deviation need not be lower than the uncorrected standard deviation because the means and standard deviations are calculated using the full data set whereas the fit was performed using only the thinned data set.

Figure 8 is not as straight forward to interpret as it first appears. The displayed mean O-B is the global mean and could be averaging out considerable variation across the globe. Figure 9 shows the mean O-B of each latitude band for each channel on the one plot. The five latitude bands for channel x are shown at x, x+0.2, x+0.4, x+0.6 and x+0.8. It can now be seen that although the global mean O-B is very close to zero between channels 60 and 90 for 1+2, this is hiding considerable positive and negative excursions in the 5 latitude bands. It was decided that calculating a

root mean square (R.M.S.) of the mean O-B across the latitude bands would be a better measure of the quality of the bias correction. The latitude bands were all given equal weight in the R.M.S. (Calculating the R.M.S. O-B for all bias corrected observations was not done because the intention was to separate the effect of the bias correction on the mean from the effect on the standard deviation). An R.M.S. value was also calculated for the standard deviation of O-B in the same way. Figure 10 is a very similar plot to figure 8 but shows the R.M.S. values. The bias corrections do not result in zero R.M.S. mean O-B for two reasons. Firstly, the bias corrections were calculated from the thinned data set but were applied to the full data set. Secondly, even if the correction were applied to the thinned data set, this would only result in zero mean O-B *globally* and there is no reason that the mean O-B for the individual latitude bands would be zero. The R.M.S. standard deviation need not be lower than the uncorrected R.M.S. standard deviation because they are calculated using the full data set, not the thinned data set and also because the R.M.S. gives each latitude band exactly equal weight whereas the thinning only gives the latitude bands approximately equal weight in the fit. The scan-only bias correction is clearly the worst on figure 10. According to the R.M.S. statistic, there is little to separate 1+2, 1+2+5 and 3+5 in terms of the effect on the mean O-B although 3+5 is arguably the worst of the three. The effect of the predictors on the standard deviation is more pronounced, 3+5 and 1+2+5 reduce the standard deviation by about 5 to 10 percent in the 60–90 range while 1+2 has little effect. Figure 11 displays the results from using each of the predictors 1, 2, 3 and 5 separately (note that the line colours have been 'overloaded' from figure 10). Here, 5-only is by far the worst correction and, interestingly, reduces the standard deviation for channels 60–90, like 3+5 and 1+2+5. There is little to separate predictors 1, 2 and 3.

Figures 12 and 13 are similar plots to figures 10 and 11 but for the AMSU-A channels, again using April data. The plots on the left are the clear data and the plots on the right are the clear + cloudy data. Notice that the scan-only correction gives a significant reduction in the standard deviation, indicating a large scan dependent bias. The low numbered channels are sensitive to the surface and the higher numbered channels are sensitive to the stratosphere; the model background is not expected to be particularly accurate in either case, hence the large O-B deviations and variations. AMSU-A channel 7, is known to suffer from interference which is probably responsible for its peculiarly high standard deviation. All the predictor combinations seem to produce similar results for channels 4–10 but the scan-only correction is noticeably worse. Strangely, 3+5 and 3 both seem to do quite well for the high sounding channels.

As well as performing the R.M.S. calculation over the latitude bands, the R.M.S. was calculated over the channels, giving all channels equal weight. Figure 14 shows the R.M.S. mean and standard deviation for each of the latitude bands (0–4) and globally (5), where the R.M.S. has been calculated over the 117 AIRS channels. The R.M.S. mean O-B is lower globally because the deviations from each latitude band have been averaged out before calculating the R.M.S.; the global value would be zero if the correction had only been applied to the thinned data set. The standard deviation of O-B seems to be lower in the Northern Hemisphere, perhaps indicating a more accurate background. This plot again shows that scan-only and 5-only are the poorest corrections and that 3+5, 1+2+5 and 5-only significantly reduce the standard deviation. Figures 15 and 16 show the equivalent plots for the AMSU-A channels for clear data and clear + cloudy data. The R.M.S. was only calculated

over AMSU-A channels 4–10. Scan-only is clearly the worst while 1+2, 1+2+5 and 1 are all fairly good.

The statistics may be boiled down still further by calculating the R.M.S. over all latitude bands and all channels. Figure 17 shows the resulting R.M.S. mean O-B and R.M.S. standard deviation for the AIRS channels, AMSU channels 4–10 using clear data and AMSU channels 4–10 using clear + cloudy data. The number of predictor combinations was greatly extended for this plot and the haphazard ordering is a historical artifact! The R.M.S. standard deviation of O-B for clear + cloudy data has had 0.04 subtracted from it so that the R.M.S. can be plotted on a smaller range. These results are also tabulated in table 3. The AMSU results are the easiest to interpret: any combination other than 0, 7 and 8 seem to give reasonable results. For the AIRS results, combinations 0, 5, 7, 5+7, 8 and 5+8 all seem relatively poor. It might be argued from figures 9 and 10 that the difference between other predictor combinations is not significant. As previously noted, combinations involving predictor 5 all seem to reduce the overall standard deviation by a few percent (although from figure 10, there are probably 5 to 10% reductions in particular channels).

6 Results for Nov/Dec and Jan/Feb Data

The same predictor combinations tested using April data were also tested using the Nov/Dec and Jan/Feb data. Figures 18 and 19 show the overall R.M.S. mean O-B and R.M.S. standard deviation calculated over all AIRS channels and latitude bands for Nov/Dec and Jan/Feb; compare with figure 17. This data is tabulated in table 4. It can be seen that although Nov/Dec and Jan/Feb are very consistent with each other, they are not that consistent with the April results. For the winter data, predictors 1, 2 and 3 alone look a lot less skillful in reducing the mean bias of AIRS channels than they were when using April data. Similarly, a number of the predictors combinations produce less good corrections for the AMSU channels. The results for the standard deviation in Nov/Dec and Jan/Feb are similar to April.

Predictor combinations 1+2 and 1+2+5 both reduce the R.M.S. mean O-B to a similar, large extent but 1+2+5 reduces the standard deviation by a few percent more. The combination 1+2+3+5+8 produces the lowest mean O-B and also the lowest standard deviation. Figure 20 shows the R.M.S. mean and standard deviation of O-B calculated across the five latitude bands for all the bias corrected AIRS channels and for predictor combinations 0, 1+2, 1+2+5 and 1+2+3+5+8 using Jan/Feb data. The 1+2 correction in this plot bears comparison with the April 1+2 correction, shown in figure 10. Maps of the mean and standard deviation of O-B were also produced for predictor combinations 1+2, 1+2+5 and 1+2+3+5+8 and these may be viewed on an internal Met Office web page [5]. Many of these images show peculiar behaviour around the North Pole. The Cressman analysis scheme was re-written to investigate this anomaly and it was concluded that the effect was real and due to the way information was spread from the small number of data points near the pole [5]. The bias correction currently identifies observations over the sea using the model surface type. An improved sea-ice cut may result in a better bias correction.

It has been seen that the use of predictor 5 seems to be associated with a significant reduction in the standard deviation of channels 60–90. Whenever a predictor is successful in reducing spatial variations of the mean O-B within a latitude

	AIRS		AMSU-A Channels 4–10			
	Mean	S.D.	CLR Mean	C+C Mean	CLR S.D.	C+C S.D.
uncor	0.795	1.068	0.637	0.687	0.650	0.800
0	0.264	1.067	0.116	0.152	0.523	0.566
35	0.138	1.019	0.060	0.049	0.520	0.561
12	0.121	1.056	0.057	0.040	0.519	0.561
125	0.108	1.010	0.055	0.038	0.519	0.560
1	0.135	1.057	0.059	0.041	0.519	0.561
2	0.133	1.058	0.075	0.060	0.520	0.563
3	0.132	1.063	0.074	0.061	0.522	0.564
5	0.293	1.041	0.071	0.069	0.521	0.562
13	0.126	1.056	0.054	0.041	0.519	0.561
15	0.160	1.018	0.056	0.039	0.519	0.560
135	0.133	1.013	0.052	0.038	0.519	0.560
1235	0.110	1.007	0.052	0.038	0.519	0.560
7	0.220	1.071	0.096	0.137	0.525	0.569
37	0.132	1.061	0.074	0.063	0.521	0.563
57	0.237	1.038	0.058	0.051	0.519	0.562
357	0.132	1.013	0.054	0.047	0.519	0.561
8	0.250	1.067	0.111	0.150	0.523	0.566
18	0.101	1.057	0.051	0.034	0.519	0.561
28	0.109	1.057	0.064	0.053	0.520	0.563
128	0.097	1.056	0.049	0.034	0.519	0.560
1278	0.090	1.054	0.048	0.030	0.518	0.560
38	0.105	1.062	0.067	0.052	0.522	0.564
58	0.284	1.040	0.065	0.064	0.521	0.562
358	0.106	1.018	0.055	0.041	0.520	0.561
1358	0.099	1.012	0.042	0.031	0.519	0.560
12358	0.087	1.007	0.043	0.031	0.518	0.560

Table 3: The R.M.S. mean and standard deviation of O-B calculated over both the latitude bands and channels for both AIRS and AMSU-A and for various combinations of predictors, see the text for details.

band, this will result in a lower overall standard deviation for that band. A reduction in the overall R.M.S. standard deviation of O-B could, therefore, indicate a better fit. Channels 60–90 are important for the retrieval of water vapour. Figure 21 reproduces the percentage reduction in the standard deviation of O-B from figure 10. The bottom plot shows the average observed brightness temperature for clear fields of view from 6 hours of AIRS data. The blue crosses show the number of degrees of freedom for signal (DFS), where a low value indicates that the channel is important for the retrieval of humidity information, for the 52 most important channels [6]. Bias corrections involving predictor 5 are therefore making some kind of alteration to the channels we are interested in retrieving information from. It is therefore important to establish beyond doubt whether the alterations are beneficial or detrimental. The only way to be certain is to compare the impact of using different bias corrections in a trial assimilation.

It is desirable to keep the bias correction as simple as possible while still making

	Nov/Dec		Jan/Feb	
	Mean	S.D.	Mean	S.D.
uncor	1.003	1.217	0.897	1.072
0	0.435	1.214	0.411	1.071
35	0.216	1.174	0.233	1.019
12	0.225	1.197	0.135	1.066
125	0.190	1.164	0.125	1.016
1	0.315	1.198	0.201	1.062
2	0.312	1.201	0.356	1.063
3	0.291	1.206	0.303	1.063
5	0.425	1.196	0.417	1.049
13	0.264	1.197	0.187	1.060
15	0.281	1.174	0.227	1.024
135	0.188	1.165	0.145	1.015
1235	0.133	1.162	0.102	1.012
7	0.396	1.217	0.381	1.074
37	0.224	1.205	0.160	1.065
57	0.407	1.192	0.370	1.052
357	0.191	1.170	0.154	1.018
8	0.358	1.213	0.334	1.071
18	0.170	1.197	0.131	1.061
28	0.123	1.199	0.150	1.063
128	0.094	1.195	0.102	1.059
1278	0.093	1.194	0.096	1.058
38	0.115	1.205	0.148	1.063
58	0.366	1.195	0.367	1.045
358	0.114	1.172	0.113	1.015
1358	0.092	1.163	0.111	1.011
12358	0.086	1.158	0.080	1.005

Table 4: The R.M.S. mean and standard deviation of O-B calculated over both the latitude bands and channels for both AIRS and AMSU-A and for various combinations of predictors, see the text for details.

an adequate correction. Predictor combinations 1+2 and 1+2+5 both seem to provide acceptable corrections and it would be interesting to compare their relative performance in trial assimilations, given the effect of predictor 5 on the standard deviation.

7 Conclusions

It has been shown that the AIRS bias for April 2003 is of a similar magnitude to radiative transfer errors derived from HIS data. Six air-mass predictors were used in the bias correction analysis: 1 — 850–300 hPa thickness, 2 — 200–50 hPa thickness, 3 — skin temperature, 5 — background brightness temperature, 7 — 1000-500 hPa thickness and 8 — latitude. The quality of the bias correction for various combinations of these predictors was studied for April 2003, mid-November

2002 to mid-December 2003 and mid-January to mid-February 2003. It was shown that a scan-only bias correction does not perform well and at least some air-mass predictors should be used. The use of predictor 5 results in a noticeable reduction in the standard deviation of O-B in channels important for the retrieval of water vapour information. It is recommended that predictor combinations 1+2 and 1+2+5 are both tested in trial assimilations. It is suggested that a future version of the bias correction code should include an improved method of identifying sea-ice.

8 Acknowledgements

By constructing a set of Fortran programs under the control of a flexible Unix script, Brett Harris did the considerable work required to make this analysis possible. Roger Saunders made many useful comments and corrected a few misconceptions. Andrew Collard was, as always, very willing to answer questions and provide help. Peter Rayer gave access to the HIS data together with valuable background information.

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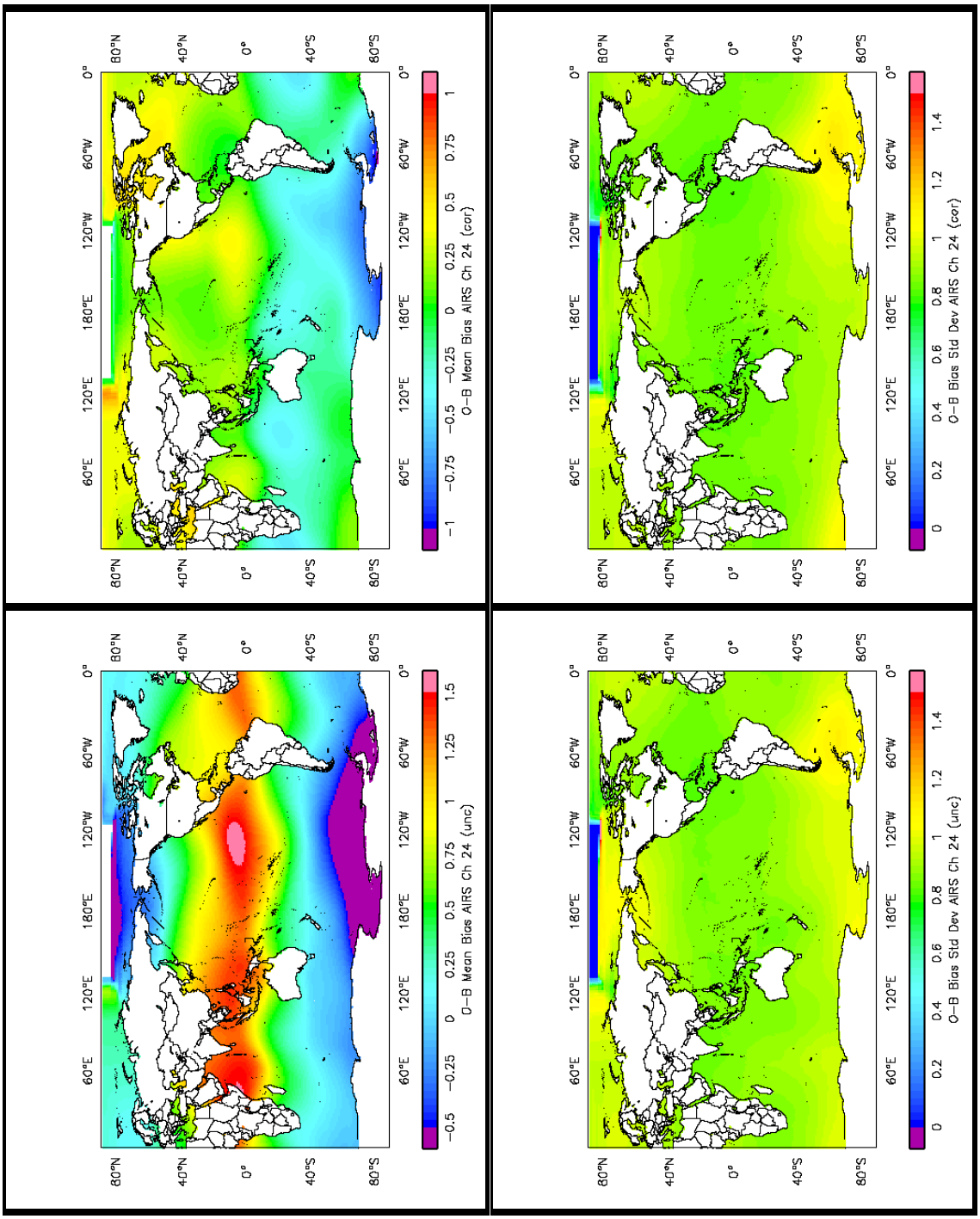

Figure 1: Maps of the mean and standard deviation of both the uncorrected and bias corrected O-B for AIRS channel 24 when using predictor 1 only and April 2003 data.

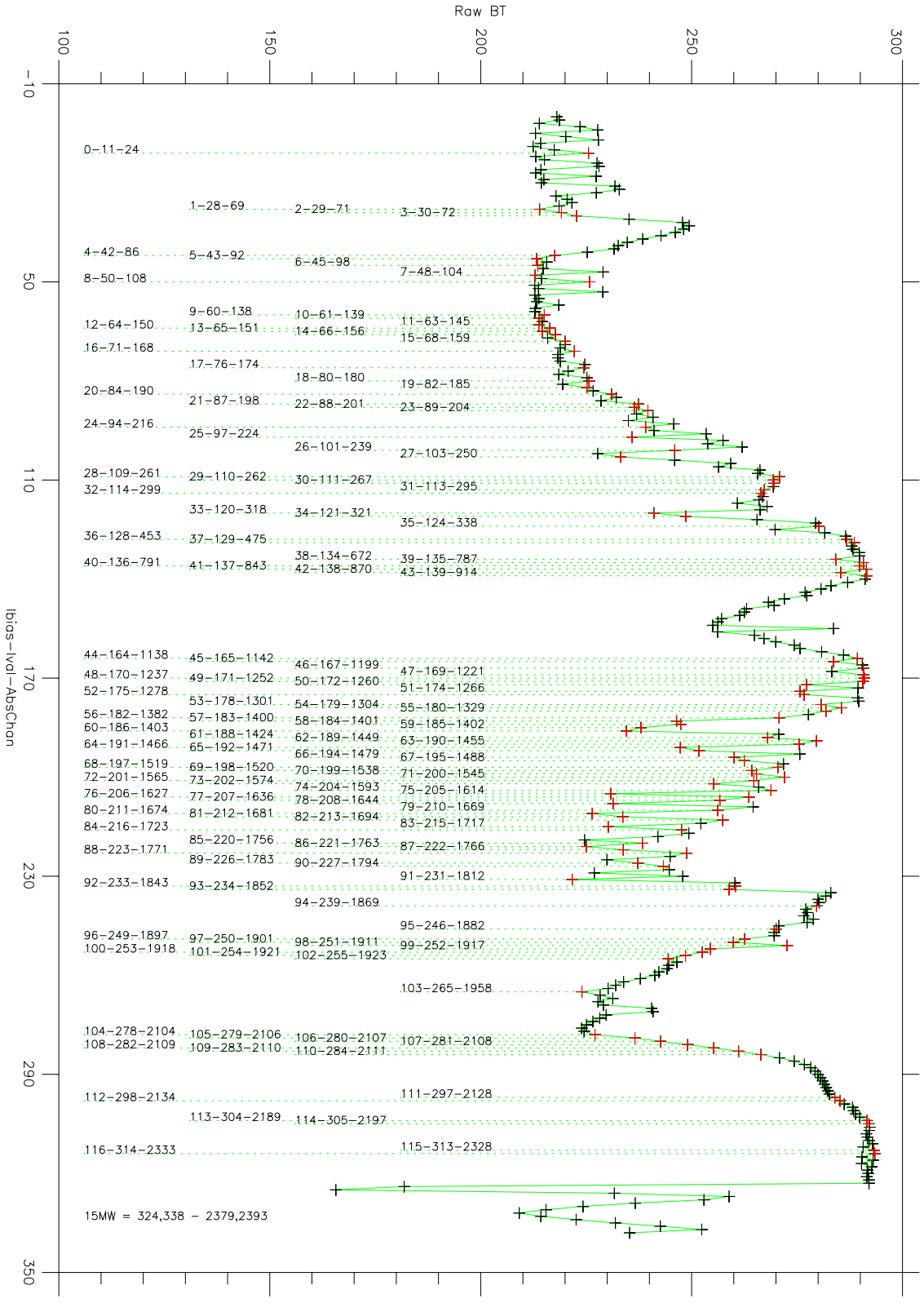

Figure 2: A typical observed brightness temperature is shown for all 339 monitoring channels with the bias corrected channels plotted in red. The bias corrected channels are labelled with their bias index, AIRS monitoring index and absolute AIRS channel number. The bias index and monitoring index both start from zero.

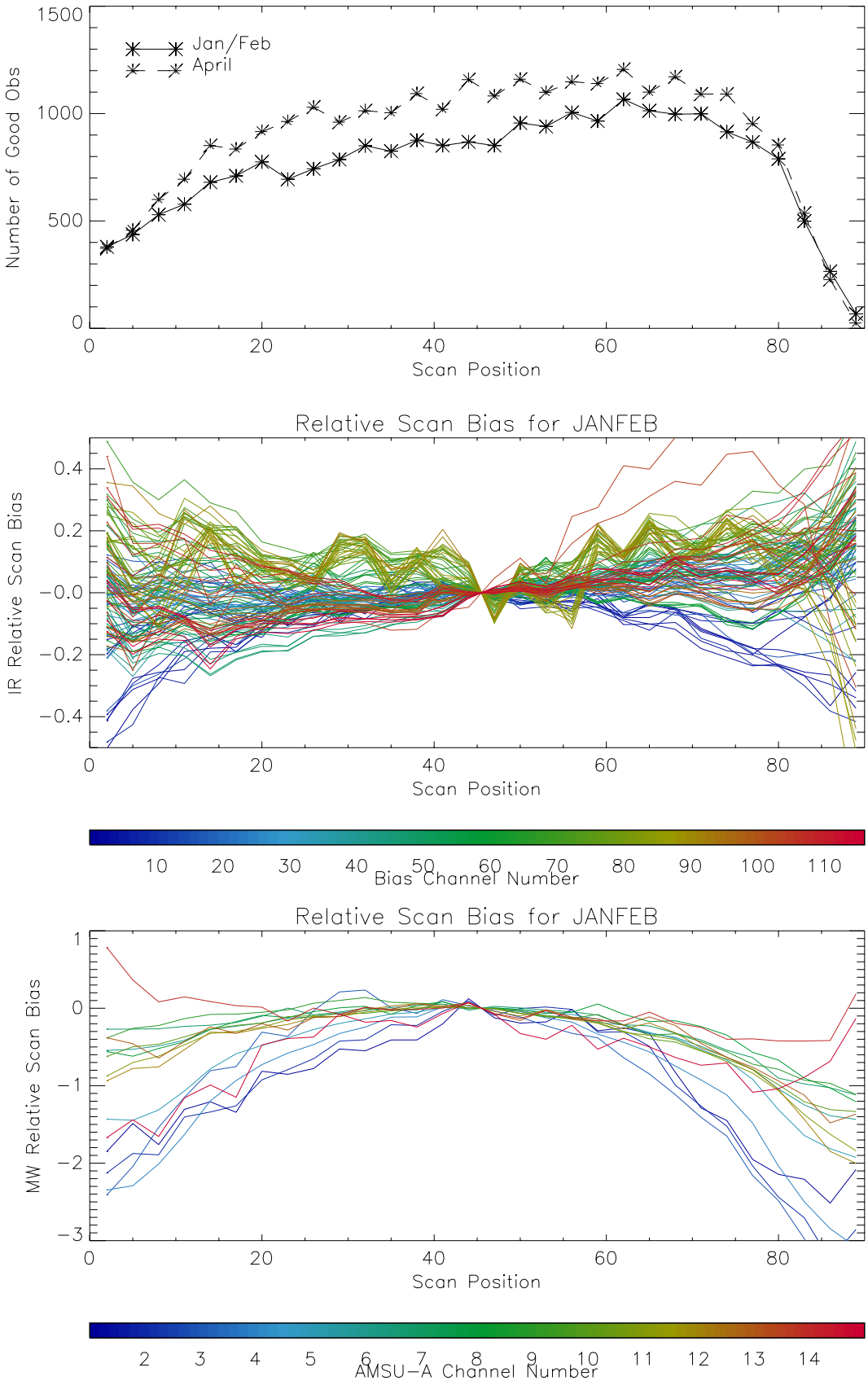

Figure 3: The top plot shows the number of observations from each scan position used in the Jan/Feb and April bias corrections. The middle and bottom plots shows the scan bias for AIRS and AMSU-A channels relative to the centre two scan positions from the Jan/Feb bias correction.

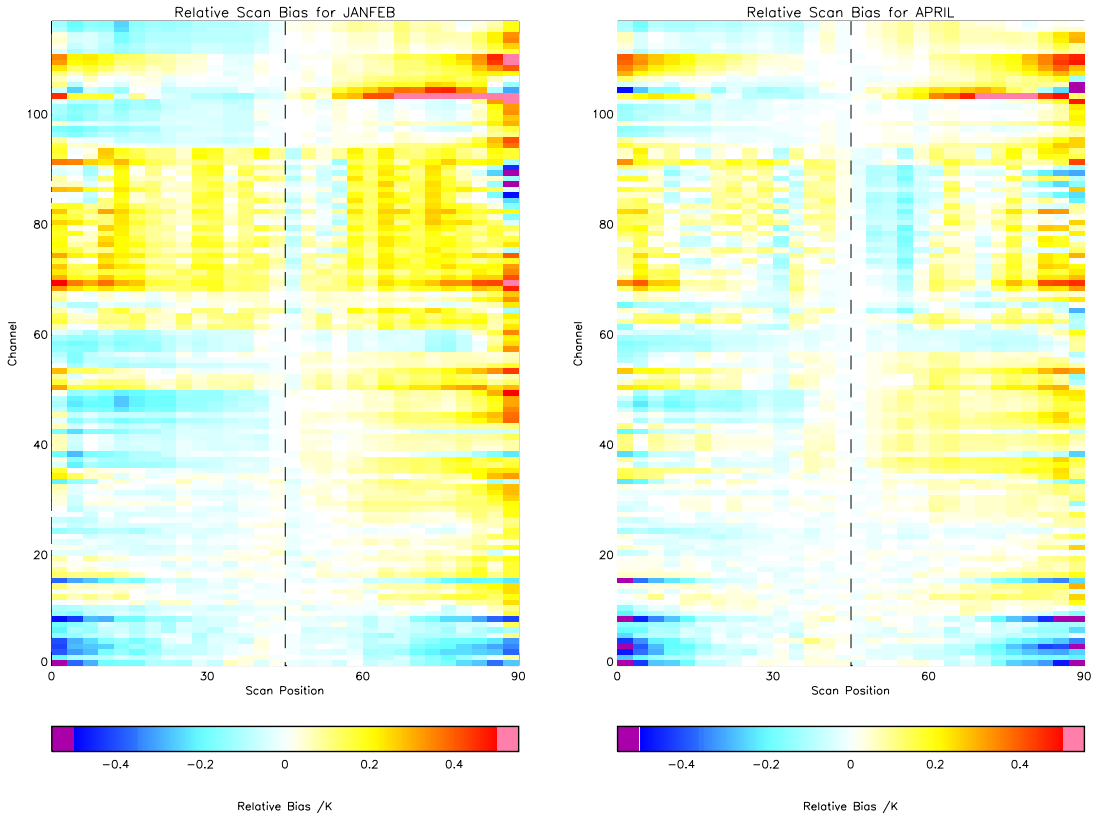

Figure 4: The scan bias for AIRS channels relative to the centre two scan positions (marked by the dotted line) for the Jan/Feb and April bias corrections.

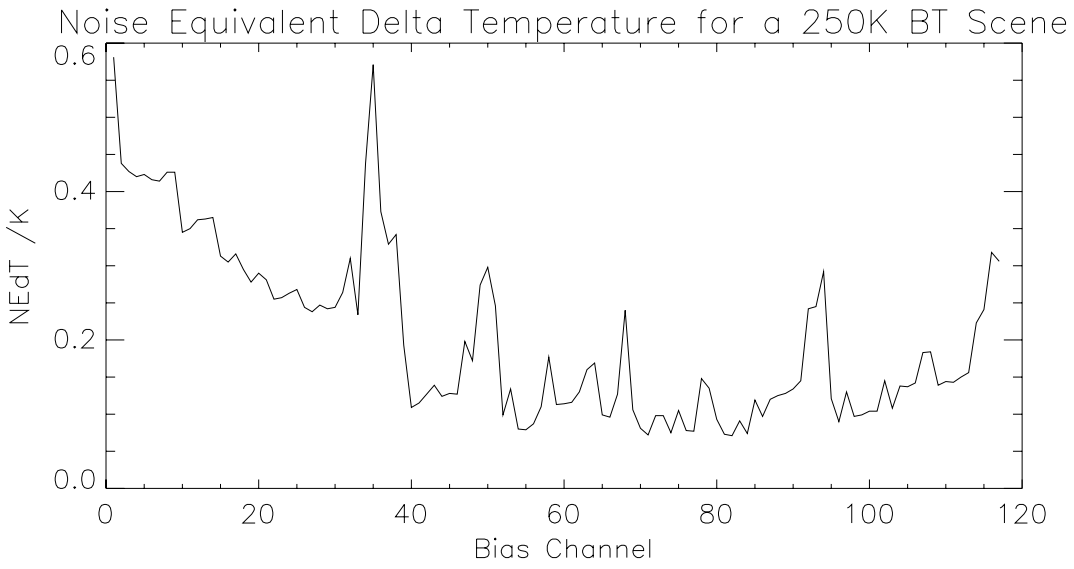

Figure 5: The noise equivalent delta temperature for a 250 K scene for the 117 bias corrected AIRS channels.

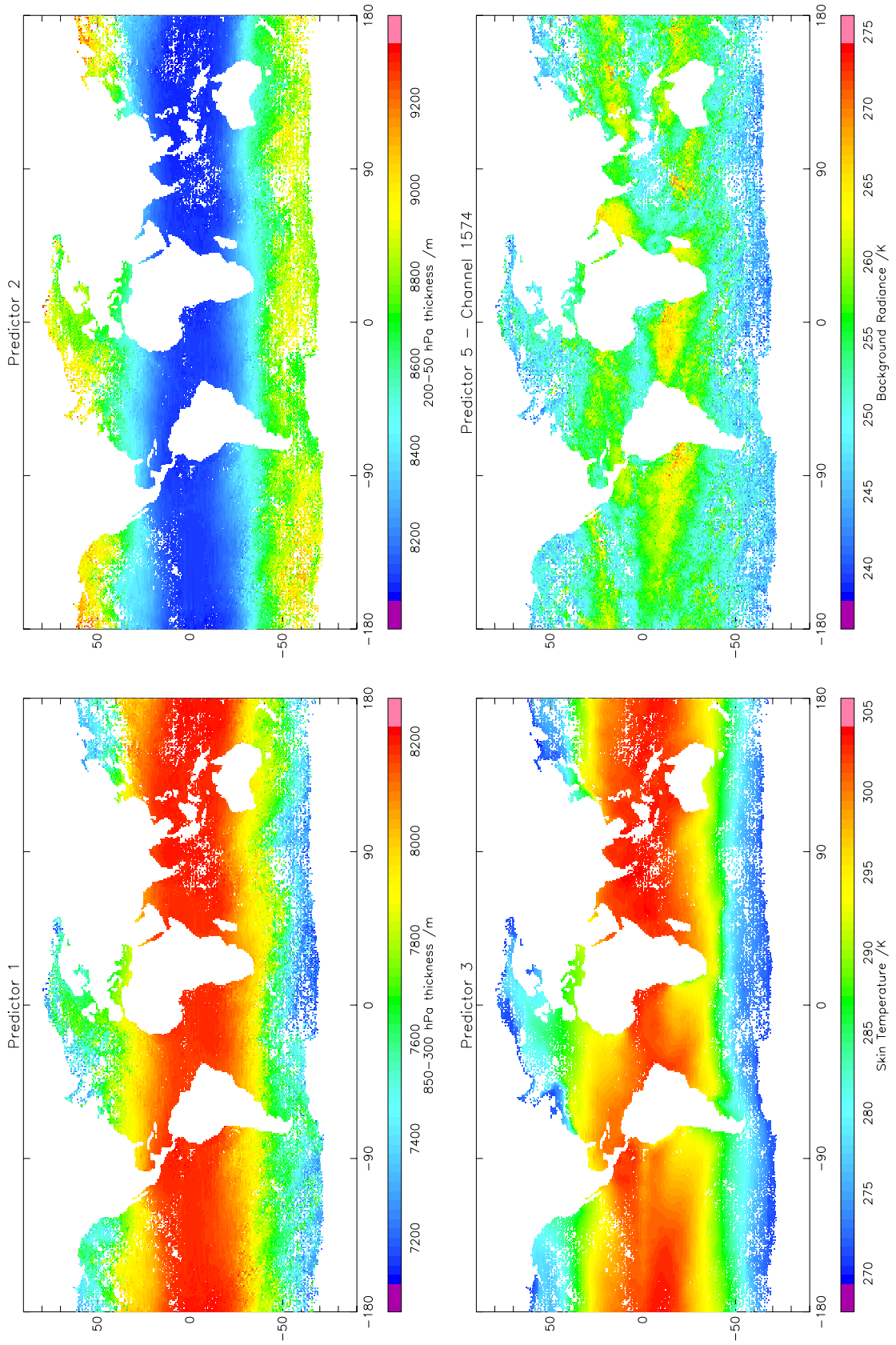

Figure 6: Maps showing the average values of predictors 1, 2, 3 and 5 (for channel 1574) for April 2003.

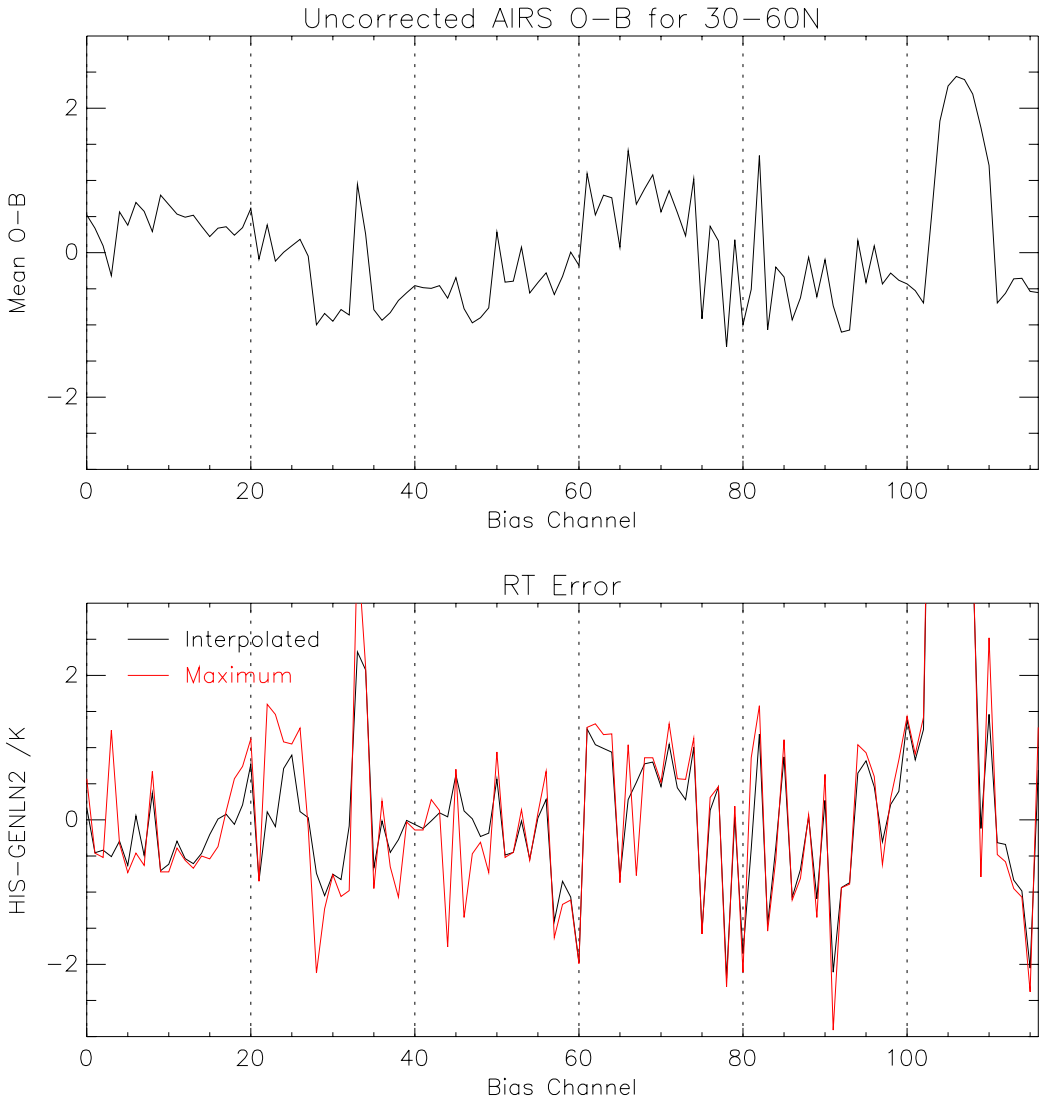

Figure 7: The top plot shows the uncorrected mean O-B for 117 AIRS channels while the bottom plot shows the difference between HIS and GENLN2 at a similar frequency, see the text for details.

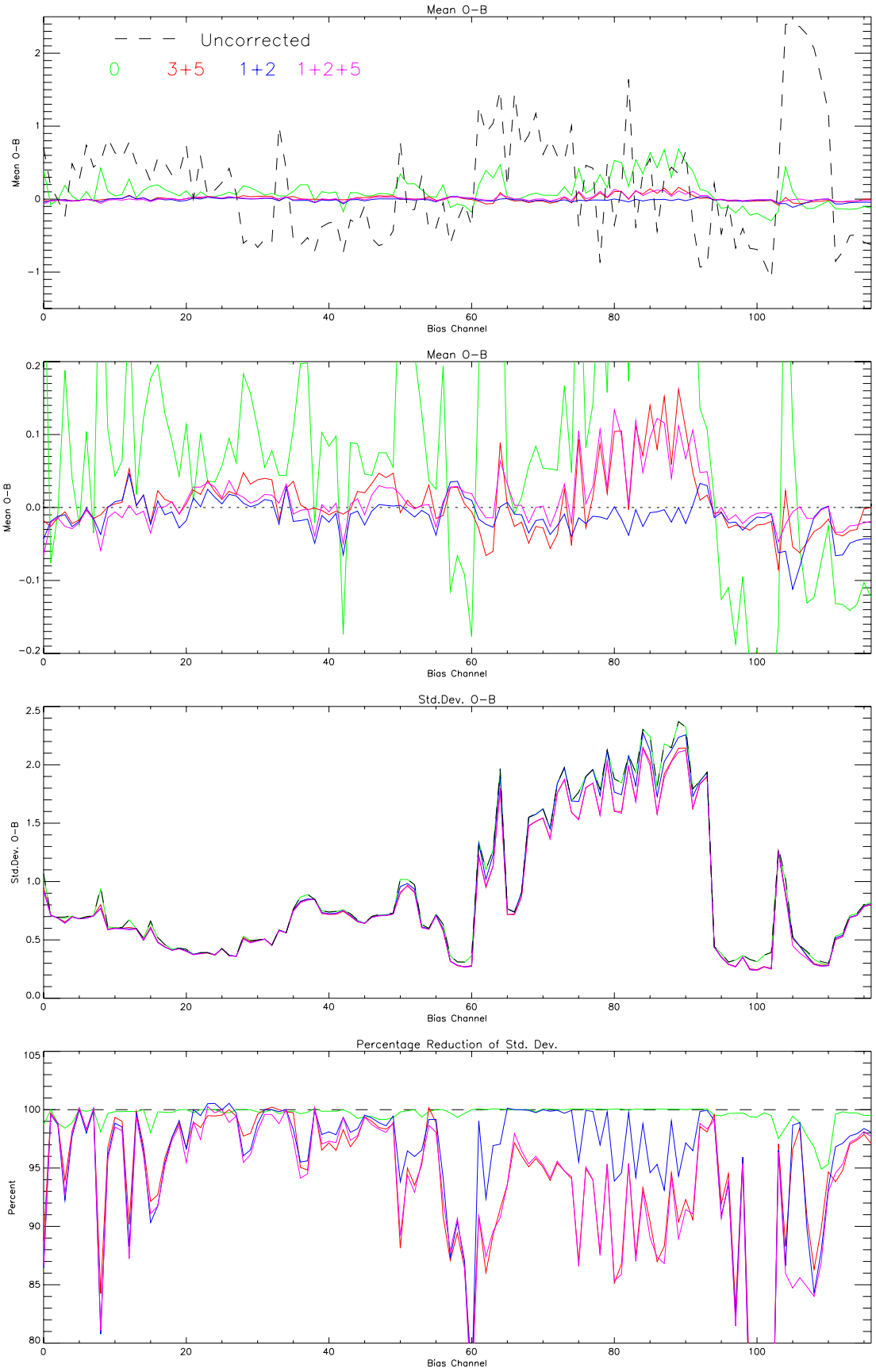

Figure 8: The global mean and standard deviation of the uncorrected and bias corrected O-B for the AIRS+MW correction and using predictors 0, 3+5, 1+2 and 1+2+5.

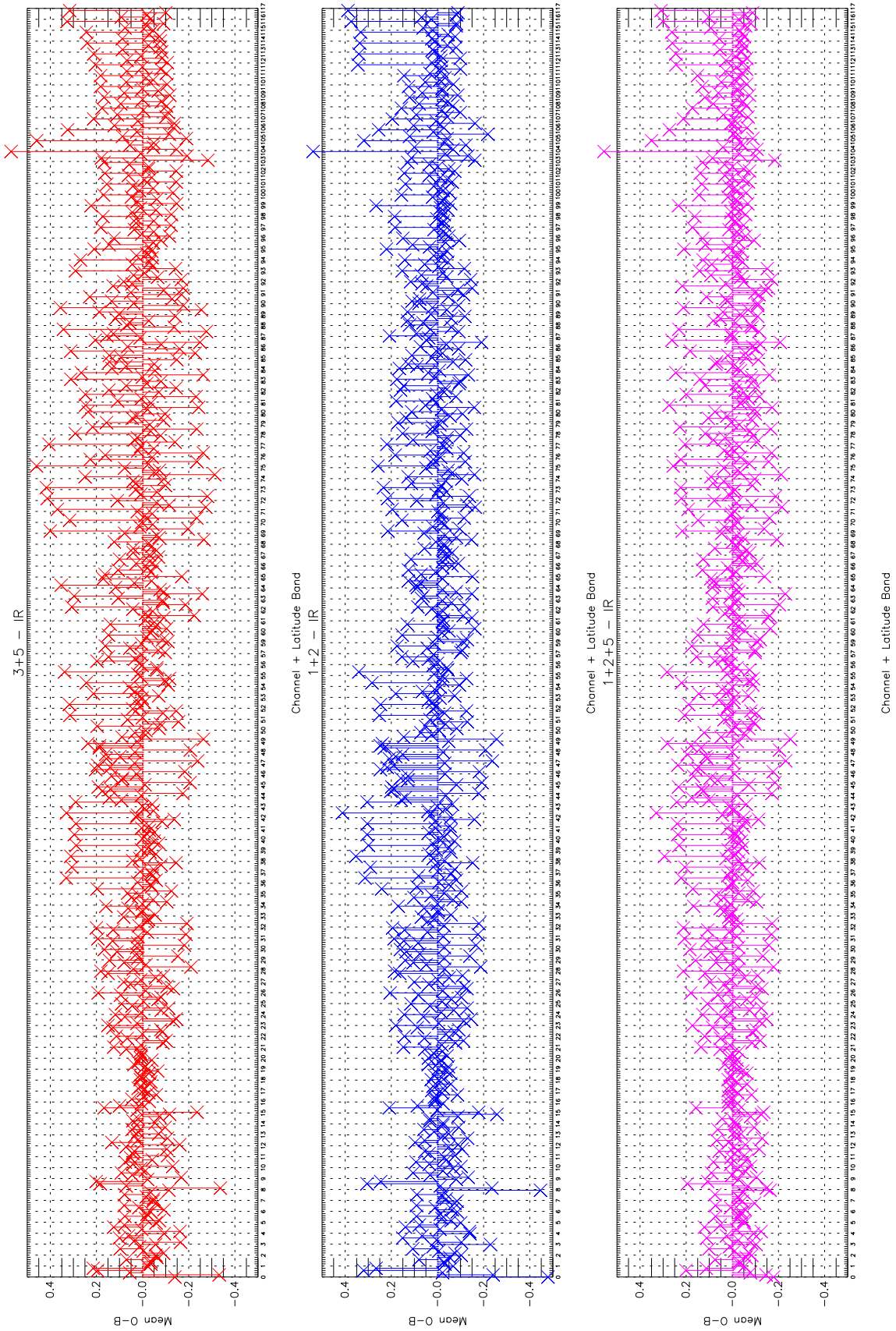

Figure 9: The mean O-B of each latitude band for 117 AIRS channels. The five latitude bands are shown at 0.2 intervals along the channel axis.

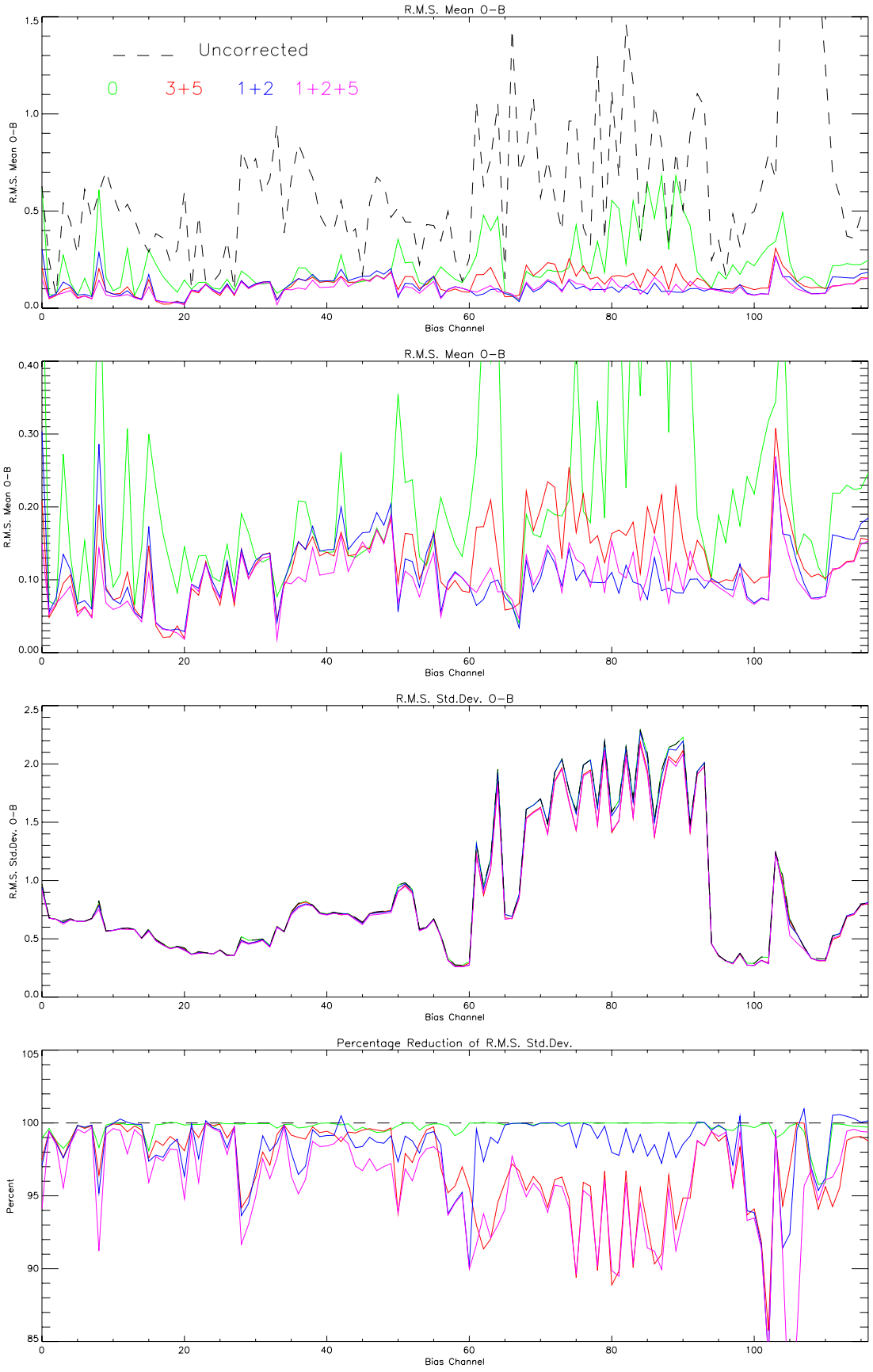

Figure 10: The R.M.S. mean and R.M.S. standard deviation of the uncorrected and bias corrected O-B for the AIRS+MW correction, using predictors 0, 3+5, 1+2 and 1+2+5.

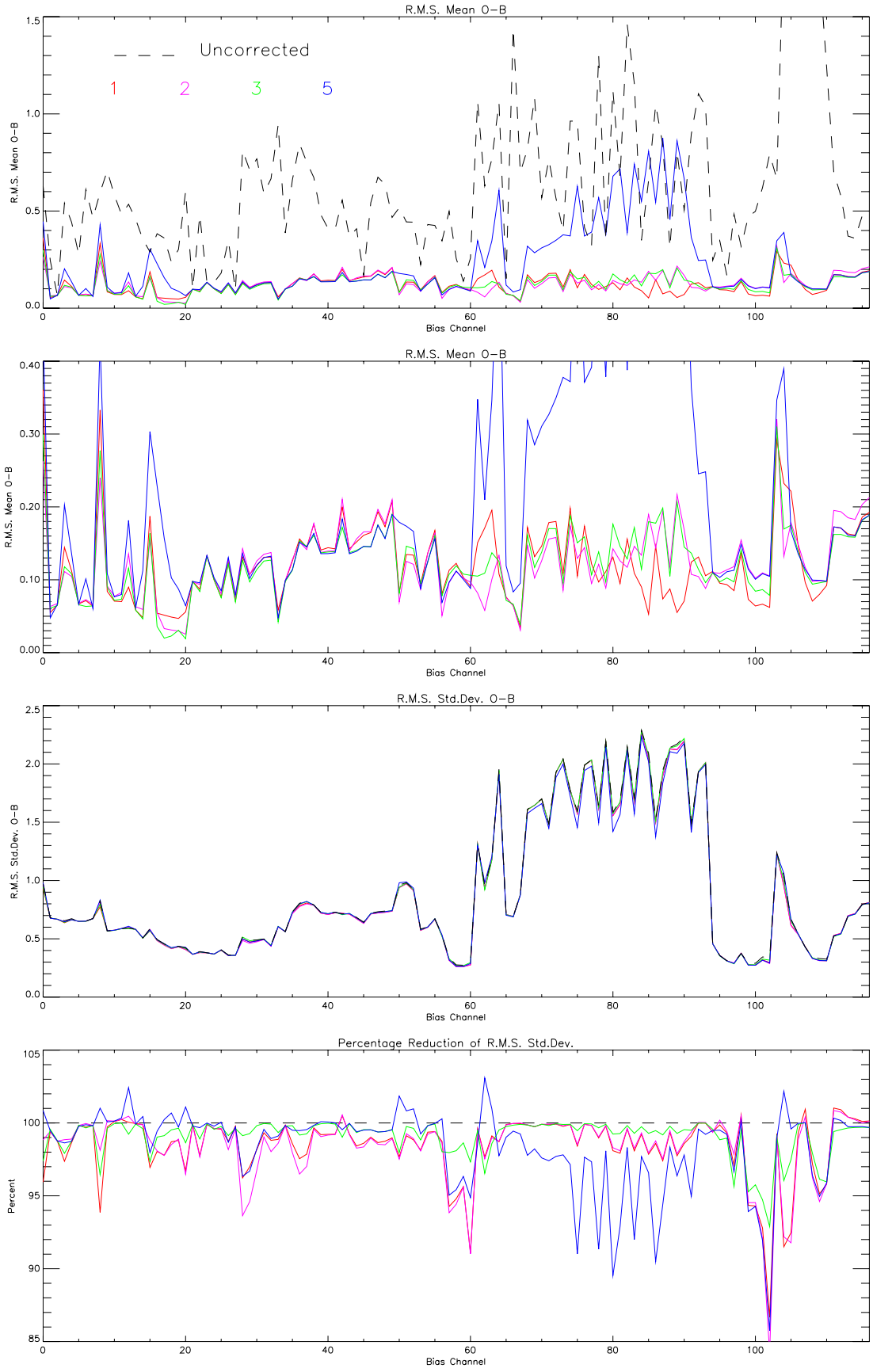

Figure 11: The R.M.S. mean and R.M.S. standard deviation of the uncorrected and bias corrected O-B for the AIRS+MW correction, using predictors 1, 2, 3 and 5.

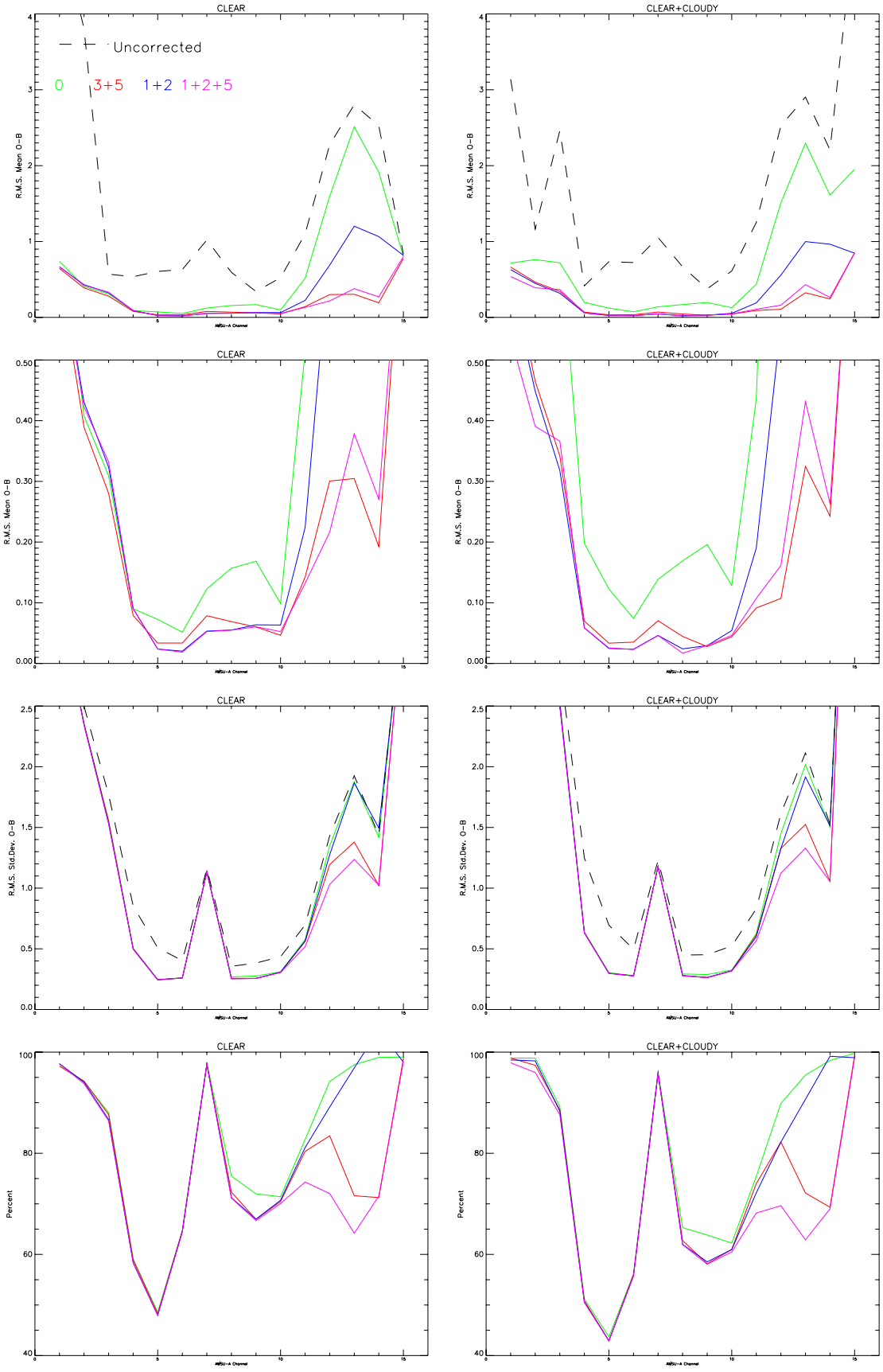

Figure 12: The R.M.S. mean and R.M.S. standard deviation of the uncorrected and bias corrected O-B for the AIRS+MW (left-hand side) and MW C+C (right-hand side) corrections, using predictors 0, 3+5, 1+2 and 1+2+5.

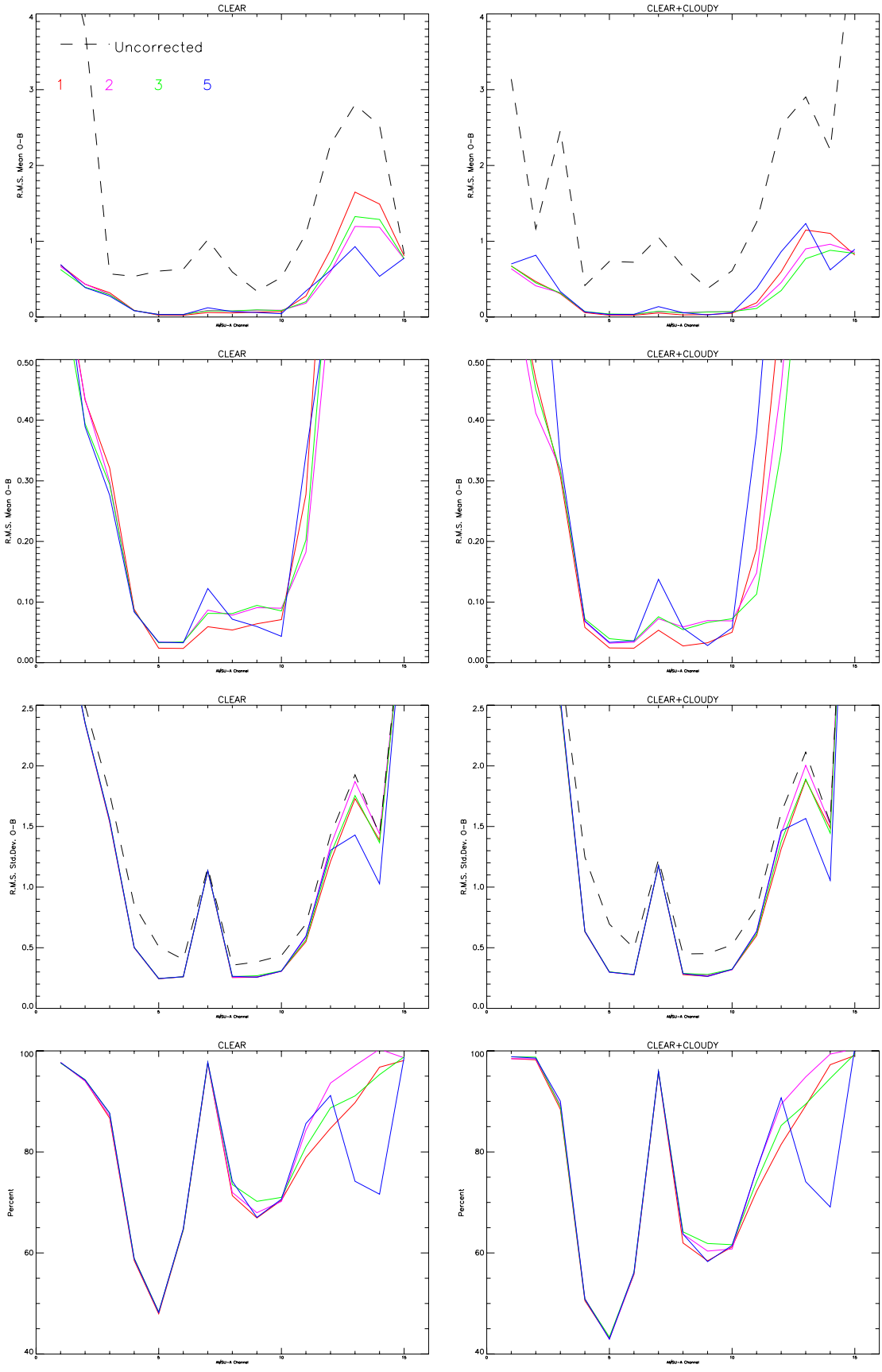

Figure 13: The R.M.S. mean and R.M.S. standard deviation of the uncorrected and bias corrected O-B for the AIRS+MW (left-hand side) and MW C+C (right-hand side) corrections, using predictors 1, 2, 3 and 5.

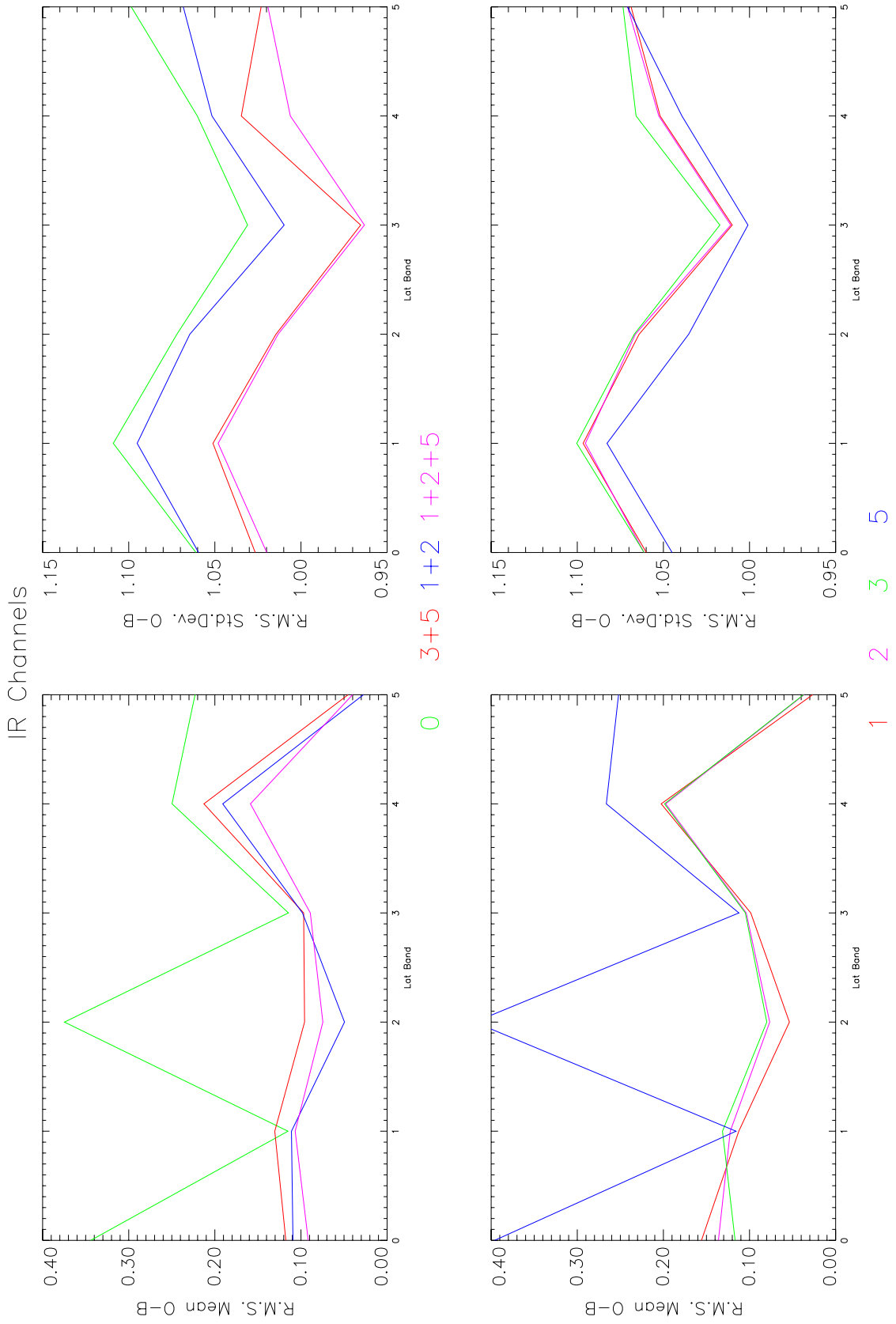

Figure 14: The R.M.S. of the mean and standard deviation of O-B calculated across 117 AIRS channels for the five latitude bands (0–4) and globally (5).

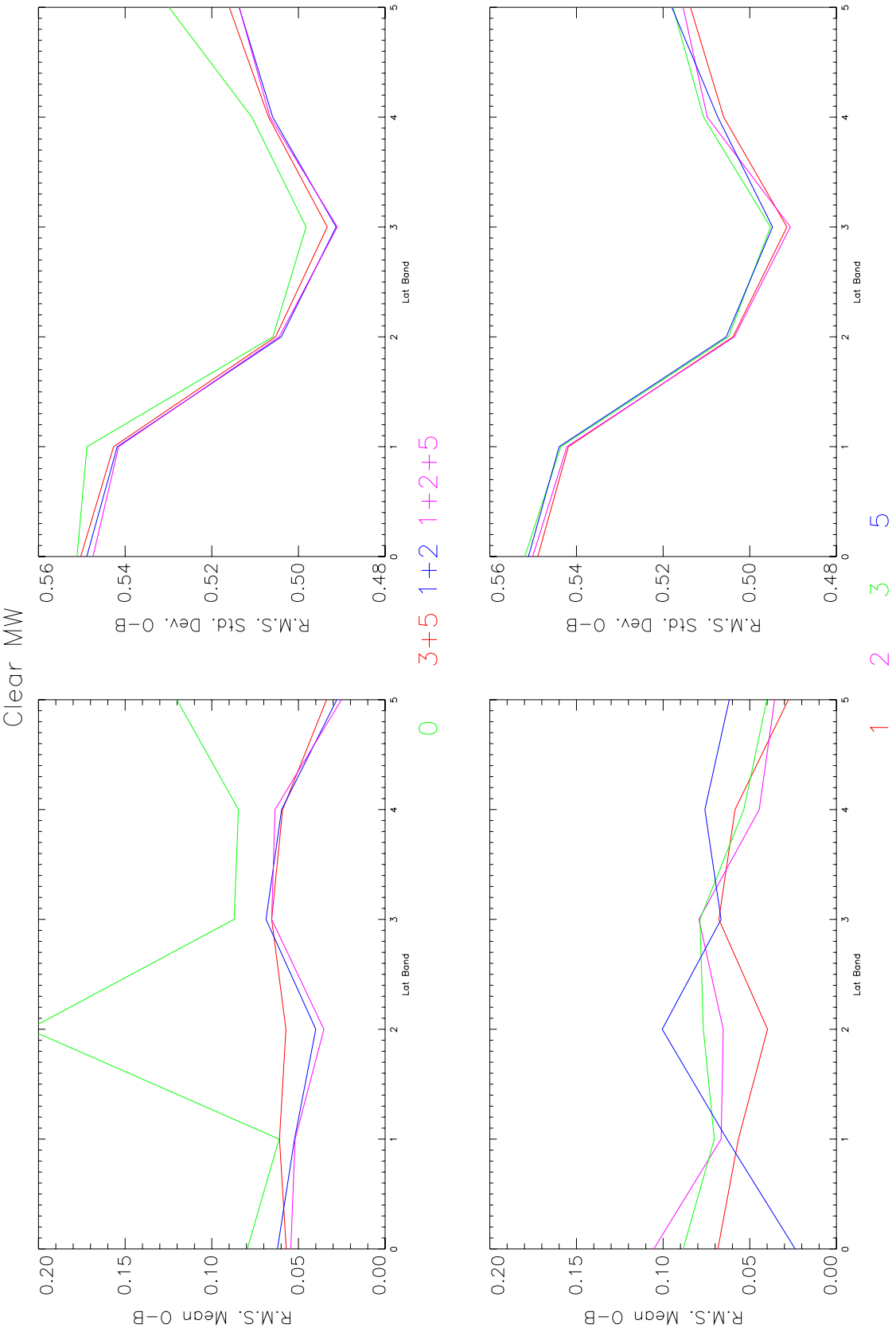

Figure 15: The R.M.S. of the mean and standard deviation of O-B calculated over AMSU-A channels 4 to 10 for the five latitude bands (0–4) and globally (5) for AIRS+MW.

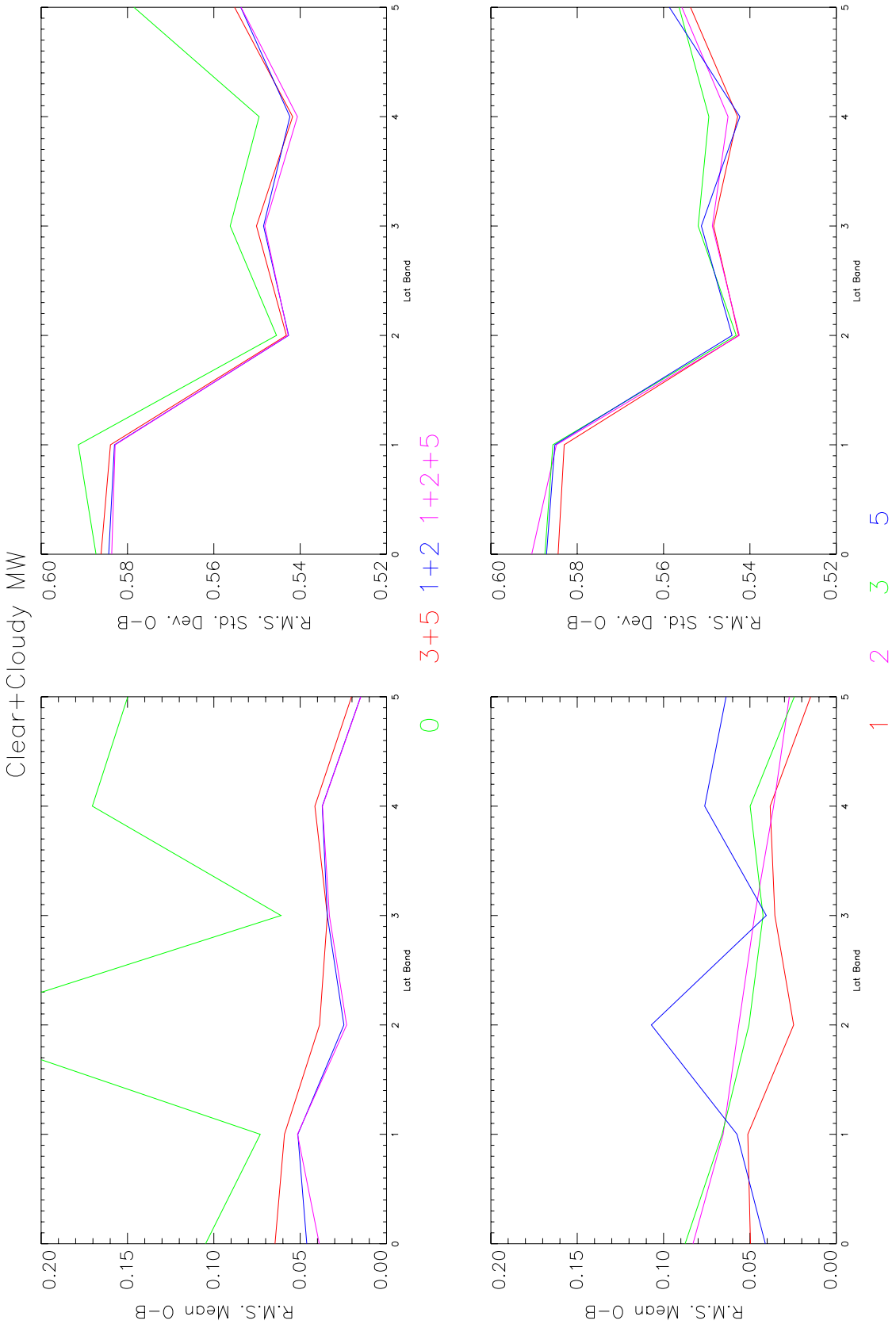

Figure 16: The R.M.S. of the mean and standard deviation of O-B calculated over AMSU-A channels 4 to 10 for the five latitude bands (0–4) and globally (5) for MW C+C.

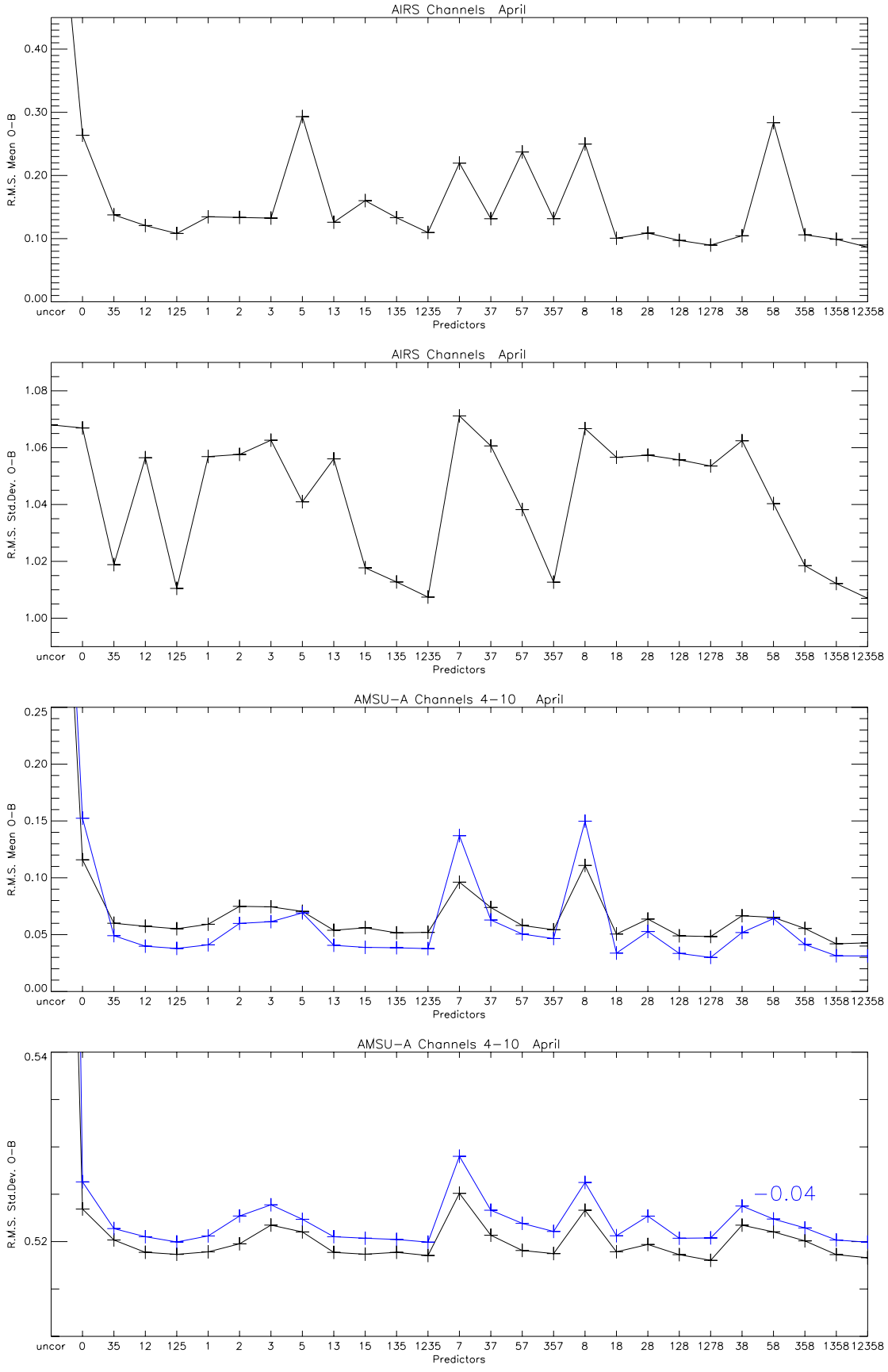

Figure 17: The R.M.S. of the mean and standard deviation of O-B calculated over all AIRS channels and all latitude bands and the R.M.S. of the mean and standard deviation of O-B calculated over AMSU-A channels 4–10 and all latitude bands using clear April 2003 data (black line) and clear + cloudy April 2003 data (blue line).

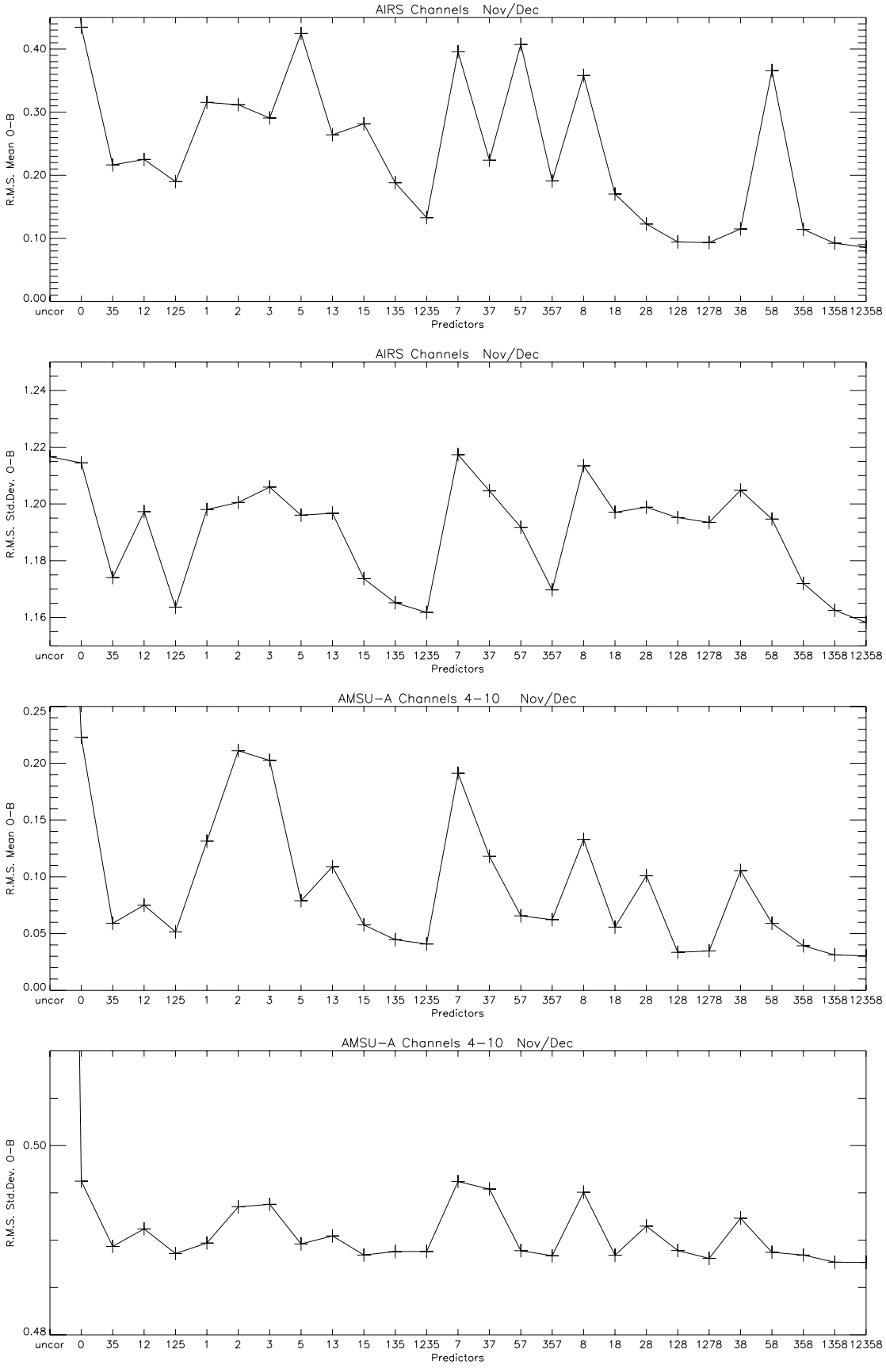

Figure 18: The R.M.S. of the mean and standard deviation of O-B calculated over all AIRS channels and all latitude bands and the R.M.S. of the mean and standard deviation of O-B calculated over AMSU-A channels 4–10 and all latitude bands using Nov/Dec 2002 data.

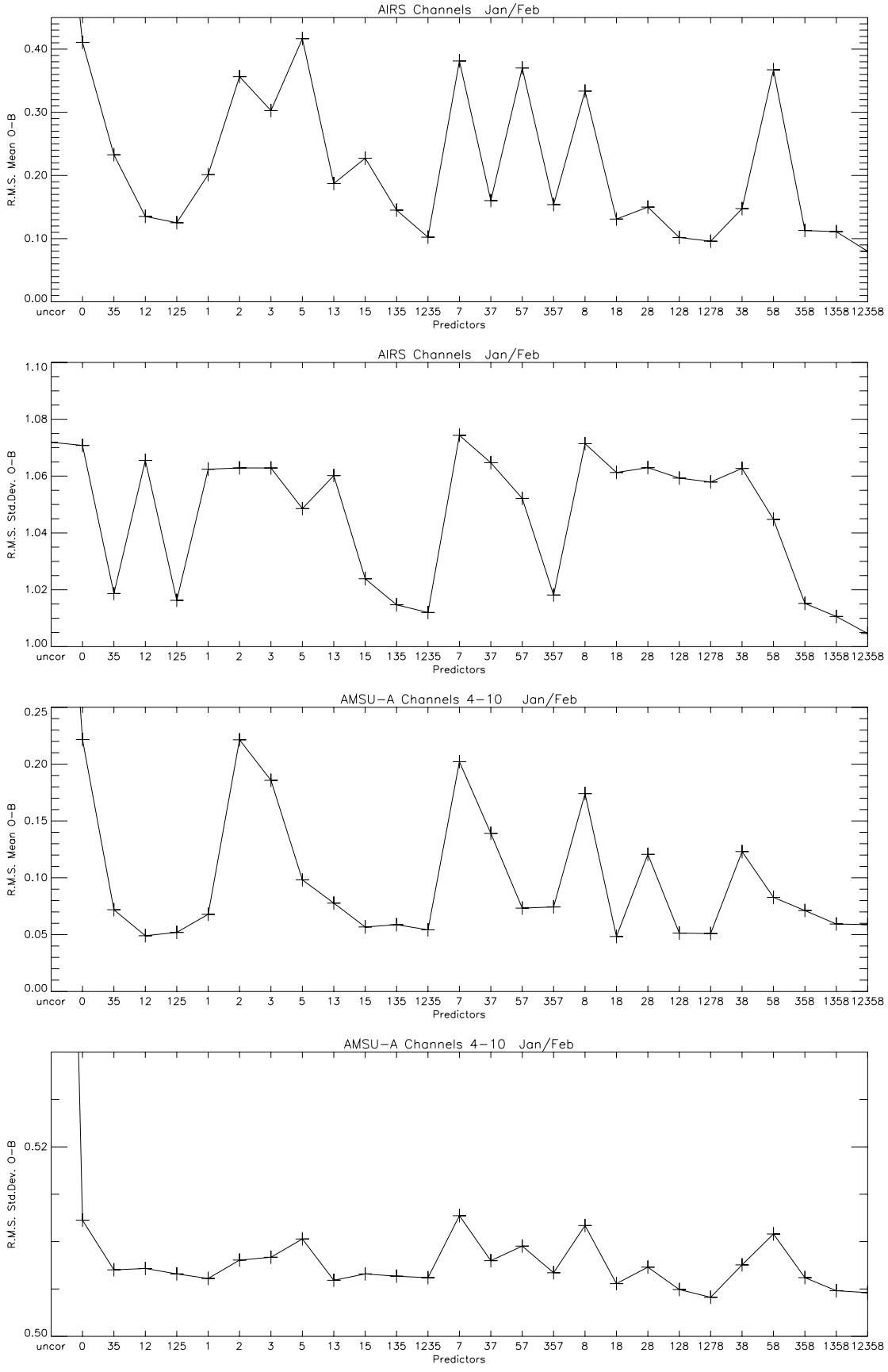

Figure 19: The R.M.S. of the mean and standard deviation of O-B calculated over all AIRS channels and all latitude bands and the R.M.S. of the mean and standard deviation of O-B calculated over AMSU-A channels 4–10 and all latitude bands using Jan/Feb 2003 data.

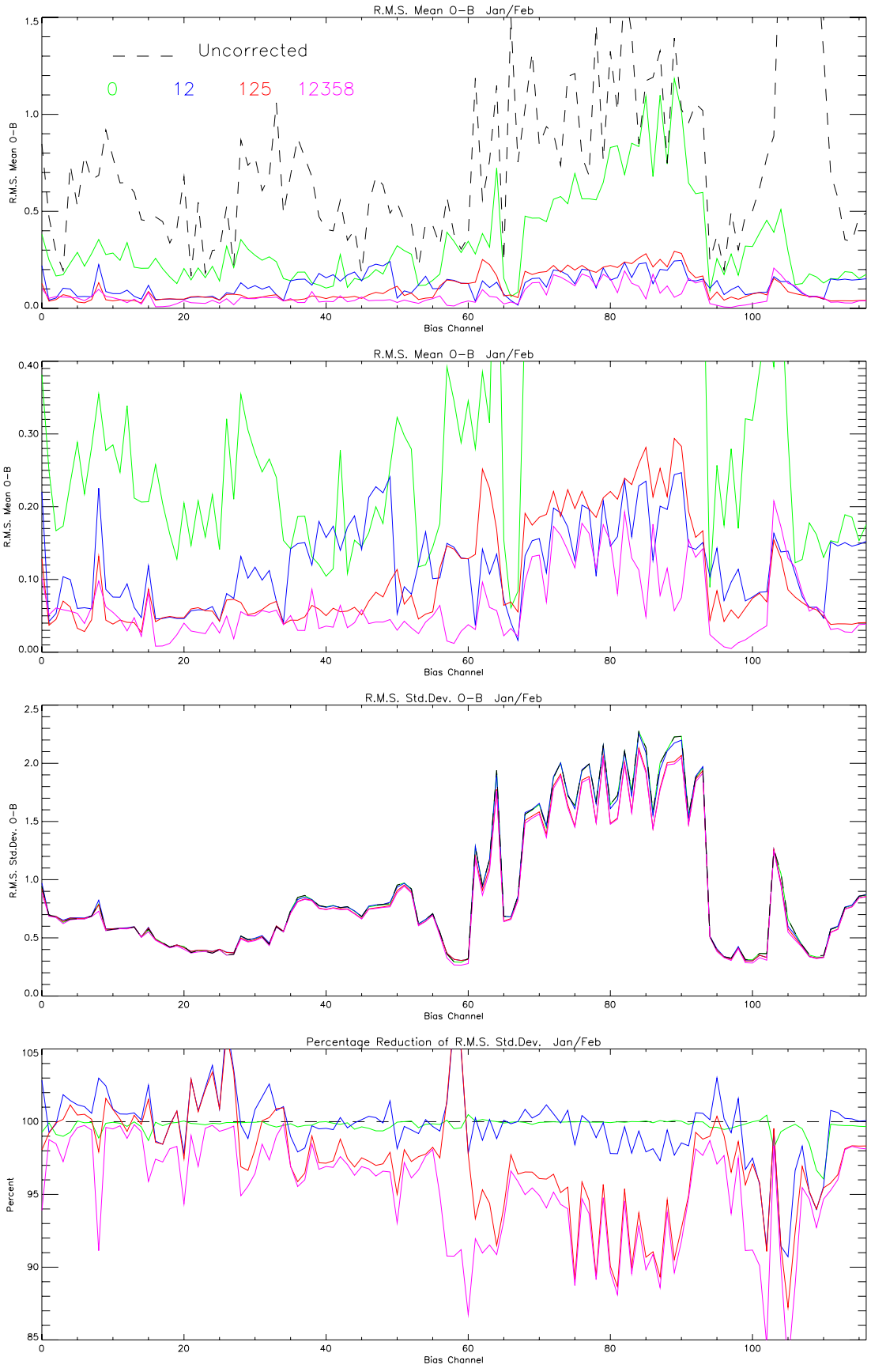

Figure 20: The R.M.S. mean and R.M.S. standard deviation of the uncorrected and bias corrected O-B for the AIRS+MW correction, using predictors 0, 1+2, 1+2+5 and 1+2+3+5+8 for Jan/Feb 2003.

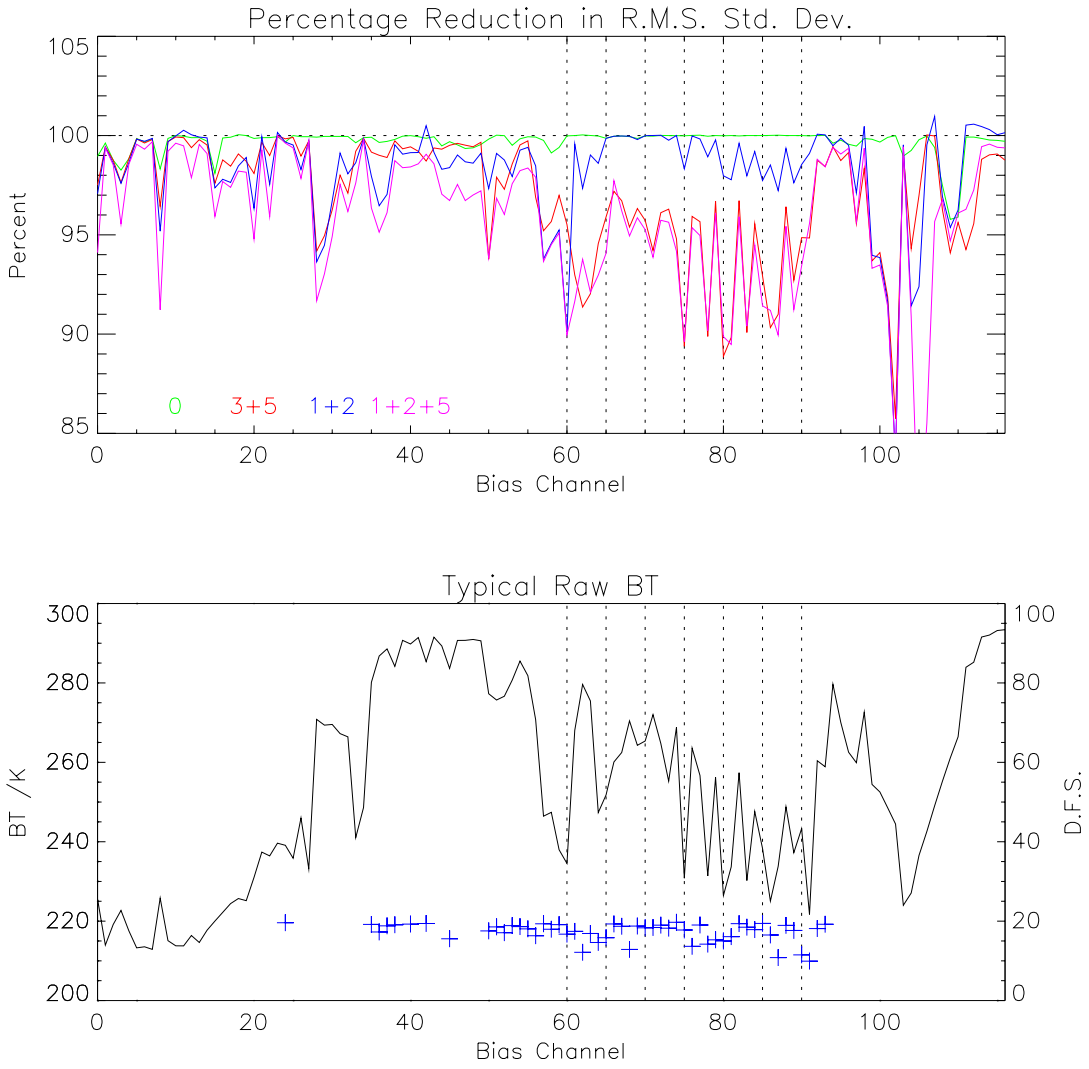

Figure 21: The top plot reproduces the percentage reduction in the standard deviation of O-B from figure 10. The bottom plot shows a typical observed brightness temperature (black line, left hand scale) from the AIRS monitoring together with the number of degrees of freedom for signal (blue crosses, right hand scale), where a low value indicates that the channel is important for the retrieval of humidity information, for the 52 most important channels [6].